FINAL REPORT

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: DAQ127C **OR Cotton CRC Project Number:**

Project Title: Managing Bollgard®II farming systems in southern Queensland

Project Commencement Date: 1 July 2003 **Project Completion Date:** 30 June 2006

CRDC Program: On Farm **OR** **CRC Program:**

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Part 3 – Final Report

Background

The project investigated sustainable best management practices for all pests of Bollgard®II cotton, and utilised Bollgard®II in farmscapes for managing pests in conventional cotton. Emphasis was placed on developing ecologically based management practices based on a sound understanding of the plant-pest-natural enemy interactions in a reduced spray Bollgard®II farming system.

Non-helicoverpa pests, including mirids, stink bugs and aphids, were the primary pest concerns in Bollgard®II. Unless these pests are managed wisely the sustainability and economic viability of Bollgard®II will be placed at risk. The use of disruptive chemical insecticides against non-helicoverpa pests will kill beneficials and flare pests. In addition, the long term use of chemicals against sucking pests will lead to resistance and the same problems that have been associated with managing helicoverpa over the past 30 years, i.e. product failures and the constant need to replace waning products with new (usually more expensive) ones. To avoid this, best management practices for all pests must be developed and incorporated into IPM programs designed around a Bollgard®II farming system. The development of a farming system that requires minimal intervention with chemical insecticides will be sustainable, and have negligible adverse impacts on the environment, livestock and human health.

The project built on previous and existing research to develop and test best management options for non-helicoverpa pests in Bollgard®II, and all pests of conventional cotton. Emphasis was placed on testing products and practices that are compatible with helicoverpa management strategies, and avoided using broad spectrum chemical insecticides. A range of cotton entomologists were consulted for advice on best management practices for non-helicoverpa pests, including Drs Lewis Wilson, Paul De Barro (CSIRO), Moazzem Khan and Richard Sequiera (QDPI&F). In addition, best management options were discussed with leading cotton consultants.

Bollgard®II is known primarily for its *Bt* toxins, and the low survival of helicoverpa that ingest these toxins. However, Bollgard®II has enormous potential to benefit the entire farming system because it is sprayed less than conventional cotton. It is anticipated that no sprays will be required for helicoverpa in Bollgard®II. Consequently, the survival and overall abundance of certain species of beneficials will be greater in Bollgard®II, and this will have flow-on benefits to the entire cotton farming system. That is, Bollgard®II has the potential to act as a nursery for some species of natural enemies, and this will benefit nearby conventional cotton and non-cotton crops in the farming system. Arthropod biodiversity will be greater in the low-sprayed Bollgard®II farming system, and this should assist the natural regulation of pests by predators and parasitoids. The project documented this potential and developed innovative ways of incorporating this into the farming system.

Important data on the impact of natural enemies on non-helicoverpa pests was generated in the project, as effective natural pest regulation may occur in some zero- or low-spray crops. Non-helicoverpa pest thresholds may have to be refined in Bollgard®II due to the greater abundance and pest management contribution of natural enemies. However the natural enemy complex of Bollgard®II will not always satisfactorily regulate the typical pest complex, and other practices were tested and incorporated into the system - particularly those that managed green mirids, stink bugs and aphids. Such practices included IPM compatible insecticides (i.e. products that reduce pest abundance but have minimal impact on natural enemies), trap crops, nursery crops and novel pest management tactics. This project combined a number of innovative concepts, as opposed to focussing on just one aspect of pest management (e.g. trap crops).

An integral part of developing sustainable pest management practices, and utilising Bollgard®II as a beneficial nursery, involves understanding the range of pests and beneficials that are most likely to be found in the crop. The crop can then be managed appropriately to ensure that the most desirable species are retained, conserved and enhanced (if possible), and the least desirable species are maintained at acceptable levels. The effective management of non-helicoverpa pests in Bollgard®II affects the crop's potential to act as a beneficial nursery, and consequently be paramount in developing sustainable pest management practices for the Bollgard®II farming system.

Farmscaping

The concept of farmscaping is to design agricultural landscapes that enhance pest management. The practice involves planting crops in a mosaic pattern to assist in managing insect pests. A range of crops can be used to trap pests and/or aid the build up of friendly arthropods, which can save insecticide sprays and reduce costs.

The goal of farmscaping is manipulating arthropod habitats to supply resources such as food for adult parasitoids and predators and provide a haven from common disturbance in cropping systems, such as insecticide applications. This involves understanding host plant and arthropod interactions and planting the correct vegetation types that make available "reservoirs" which harbour key natural enemies. These refuges can improve invertebrate biodiversity and abundance and in turn the sustainability and health of cropping systems.

The primary purpose of farmscaping in this project was to assess the potential of various crops, including Bollgard®II in assisting pest management in conventional cotton. Brad Scholz pioneered farmscaping in Australian cotton farming systems looking at many crops, such as lablab, maize, soybeans and sorghum. Sorghum stood out as the most viable companion crop for conventional cotton. Sorghum was planted in small strips (above picture)

next to cotton strips the same width, giving the same area of both crops. Preliminary evidence suggests *Trichogramma* parasitism in cotton decreases about 50 metres away from the nursery crop (maize and sorghum) and cotton interface. Based on this information farmscaping strips should be no wider than 100 metres to gain maximum benefit from the *Trichogramma* population in the nursery crop.

Farmscaping trials showed that sorghum acted as a nursery for a number of important natural enemies. There were significantly more ladybird larvae and adults in cotton within sorghum - cotton farmscapes. An exception was when conventional cotton had been managed by repeated applications of the insecticide Steward™, which is toxic to ladybirds (Figure 5). When high numbers of pirate bugs were present in sorghum there was evidence they were moving into adjacent cotton (Figure 6). Similarly spiders were most abundant in cotton adjacent to sorghum; movement was even more pronounced after the sorghum was harvested. This movement was not quantified, however beneficial diversity and abundance was enhanced by planting cotton adjacent to sorghum. Prasifka *et al.* (2004), Bommarco & Fagan (2002), Fye & Carranza (1972), also reported movement of natural enemies into cotton from adjacent sorghum.

Early in the cotton season the levels of egg parasitism were highest in low sprayed conventional cotton within farmscapes. This suggests that the strategies of releasing *Trichogramma* early and/or utilising sorghum as a nursery for *Trichogramma* have some merit.

Only inoculative releases are appropriate against *Helicoverpa* and 30,000/ha ($22/ha) has proved the most economical release rate in sorghum trials – this was the standard release rate used during the project in all crops. Ideally releases should be conducted when an egg lay is expected and while the cotton is still small (8-10 true leaves). In a cotton - sorghum farmscape it may be beneficial to conduct a second release into sorghum as the first heads emerge in the field. At this stage sorghum is particularly attractive to *Helicoverpa* egg lay and *Trichogramma* released in the field will easily find hosts ensuring the release is effective and *Trichogramma* numbers increase.

It is known that sorghum is a haven for *Microplitis* wasps and other important larval and pupal parasitoids. Sorghum - cotton farmscapes showed that they can generate an abundance of natural enemies that are known to prey on *Helicoverpa* eggs, larvae and pupae and therefore have the potential to manage *Helicoverpa* survivors in Bollgard®II. This research supports the hypothesis that natural enemies may use sorghum or maize as a haven and disperse into nearby cotton fields.

Farmscaping would be ideal for managing key bug pests in Bollgard®II. Small suicide strips of soybeans or pigeon pea planted adjacent to Bollgard®II may help manage mirids while protecting natural enemies in the cotton crop and reduce costs of spraying. Similarly sorghum strips or blocks could be used to reduce aphid infestations in adjacent Bollgard®II. Both options may reduce the need to spray insecticides and diminish the likelihood of other pest infestations e.g. whitefly. Researchers continuing to examine farmscapes need to look at relevant species rather than a suite of arthropods as seems to be a common approach. For sorghum – cotton farmscapes key species would include *Trichogramma*, pirate bugs, ladybird beetles and *Microplitis* wasps.

***Trichogramma* Insecticide Trials**
The growing interest in utilizing *Trichogramma* wasps in pest management by many Darling Downs cotton growers is being hampered by disruptive insecticide applications. Some farmers are now tyring to minimise the impact of insecticides on natural enemies, instead valuing an integrated pest management approach. It was important to understand how the various cotton insecticides impact on *Trichogramma*.

Objectives

The project aimed to:

- Develop and test best management practices for non-helicoverpa pests in Bollgard®II, while maintaining the integrity of existing helicoverpa IPM practices. The impact of all insecticides evaluated against pests will also be evaluated against key natural enemies.

- Document the pest and natural enemy complexes of Bollgard®II, and compare them with those in conventional cotton. This will enable the identification of those species that could manage pests in Bollgard®II, and that could be of pest management value in other crops, including conventional cotton.

- Design and evaluate farmscapes (on-farm crop mosaics) utilising the nursery potential of Bollgard®II, and incorporating trap crops for green mirids and stink bugs.

- Complete assessments of the impact of key natural enemies on all cotton pests as opportunities arise. This will include assessments of parasitism levels (e.g. helicoverpa, aphids, green vegetable bugs and whiteflies), and in-field survival studies of key pests at selected times.

Methods

Farmscaping trials

Trials were conducted at farms around the Darling Downs. Field samples from each trial site were taken at least twice a week. Beat sheet sampling was conducted from early in the morning until midday, before insects were driven deeper into the plants or underground by the sun. Samples were taken across the whole season from planting to harvest.

<u>Insect Assessments</u>

Pest and beneficial insects were counted twice per week in all cotton strips and in the sorghum. *Helicoverpa* eggs were counted in all cotton strips and larvae were counted in conventional cotton strips. The *Helicoverpa* larvae were classified according to body length, i.e. VS= very small (0-3 mm), S = small (3-7 mm), SM = small medium (7-13 mm), ML = medium large (13-23 mm), and L = large (>23 mm).

The levels of *Helicoverpa* egg parasitism were assessed weekly by collecting naturally laid brown eggs from each cotton strip. The eggs were collected on leaves or squares. These were stored in an esky in the field, and returned to the laboratory for sorting. The eggs were removed from the plant material using a fine paint brush dipped in water, and transferred to plastic 96-well microtitre trays where each egg was isolated in a 6 mm diameter well. The trays were sealed with sticky tape, labelled, and held at 25°C until the levels of egg parasitism could be determined.

A yellow beat sheet (Scholz *et al.* 2001) was used to sample predators. Six beat samples were completed in each strip. Predatory beetles, bugs, ants, lacewings, spiders and hover flies were counted on the beat sheets. The beat sheet method was also used to sample green mirids and green vegetable bugs.

Plant Assessments

Plant densities and node counts were recorded for each cotton strip. The numbers of plants per metre at six randomly selected sites were counted weekly. The numbers of nodes on 12 plants (2 consecutive plants at 6 sites) were also counted weekly. Fruit production was assessed by counting the numbers of damaged and undamaged fruit (squares, flowers, closed bolls and open bolls).

Plant mapping was completed prior to harvest by mapping the fruit positions on all cotton plants in a one metre length of crop at four randomly selected sites. The yields were estimated by hand harvesting 4 x 5 m lengths of paired rows of crop in each strip.

***Trichogramma* insecticide trials**

The contact and residual toxicity of 20 insecticides commonly used to control pests in cotton were tested on *Trichogramma pretiosum* (Table 1). To ensure results were consistent with field observations, field conditions were replicated as closely as possible. The impact of insecticides on *Trichogramma* was rated by averaging data from six assessments, including:

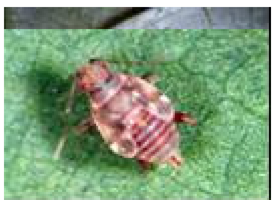
- Directly spraying *Trichogramma* adult wasps with insecticides.
- Exposing *Trichogramma* adults to insecticide residues on cotton leaves for four hours immediately after insecticides were applied over cotton plants.
- Exposing *Trichogramma* adults to insecticide residues on cotton leaves for four hours one day after insecticides were applied over cotton plants.
- Exposing *Trichogramma* adults to insecticide residues on cotton leaves for four hours two days after insecticides were applied over cotton plants.
- Exposing *Trichogramma* adults to insecticide residues on cotton leaves for four hours five days after insecticides were applied over cotton plants.
- Spraying host eggs containing 5 day old *Trichogramma* (pupae) with insecticides and assessing adult emergence and health.

Results - Bollgard®II Pest Management

The introduction of Bollgard®II has seen a change to the typical pest management regime used on most cotton farms. The *Bt* toxin that is engineered into the Bollgard®II plants negates the need to apply insecticides for *Helicoverpa* control in most situations. While this has seen an increase in the species diversity and abundance of some natural enemies in Bollgard®II, other insects such as mirids, mites, aphids and whitefly have become major pests.

Much has been made of high species diversity and abundance in Bollgard®II compared with standard conventional cotton sprayed with broad-spectrum insecticides. The findings in this project support this assertion, however it was found that Bollgard®II contained significantly fewer predatory bugs and lacewings compared with low-sprayed or IPM sprayed conventional cotton (Figure 1).

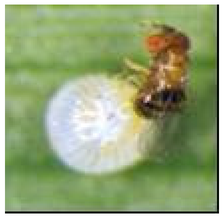
In particular lower numbers of ladybird beetles, lacewings and damsel bugs were found in Bollgard®II (Figure 2). This could be



because some predators are attracted to *Helicoverpa* larvae as important components in their diet. From these results it can be concluded that Bollgard®II has subtle effects on a range of predators. It is likely that this environmental impact would be exacerbated for parasitoids associated solely with *Helicoverpa* and other lepidopteran larvae. Ideally the farming system should have a sufficiently diverse population of natural enemies that can manage *Helicoverpa* survivors in Bollgard®II.

Egg parasitoids (particularly *Trichogramma pretiosum*) had the greatest in-field impact on *Helicoverpa* in both Bollgard®II and conventional cotton. The levels of *Helicoverpa* egg parasitism in Bollgard®II and conventional cotton peaked at 90-100% from mid-late January onwards in each year of the project. The second year of the project saw fluctuating parasitism levels, particularly in aerially sprayed regions, highlighting once again how sensitive *Trichogramma* are to broad-spectrum insecticides.

Contrary to reports of reductions in parasitism by Yang *et al*. (2005*)*, Bollgard®II did not have any apparent impact on parasitism levels by *Trichogramma*. Parasitism consistently exceeded 90% each season in all Bollgard®II crops (Figure 3). *Trichogramma* parasitism was far higher in Bollgard®II and conventional crops were appropriate insecticide management strategies were implemented than commercially sprayed conventional cotton.



IPM practices involving the conservation, enhancement and utilisation of natural enemies will be important in managing Bt resistance in Bollgard®II. Heimpel *et al.* (2005) found that egg mortality can slow the rate of Bt resistance evolution. This view is strongly supported by resistance management models used by Monsanto in which egg mortality factors are used in resistance development estimates (Stuart Addison, pers. comm.). It is important for the cotton industry to continue to develop and promote practices that preserve and enhance natural enemies in Bollgard®II crops.

The most serious pest of Bollgard®II on the central Downs over the three years of the project were green mirids. Each year of the project commercially managed dryland Bollgard®II was compared to an unsprayed crop to assess economic damage from mirids (Figure 4). Though water availability was variable across years, no difference in yield made unsprayed Bollgard®II the more economical crop. Insecticides used to needlessly control mirids decimated natural enemies, potentially contributing to aphid and whitefly infestations in Bollgard®II.

Unless these pests are managed wisely the sustainability and economic viability of Bollgard®II may be placed at risk. The excessive use of disruptive chemicals against non-*Helicoverpa* pests will kill natural enemies and flare pests. In addition, the long-term use of chemicals against non-*Helicoverpa* pests may lead to resistance and the same problems that have been associated with managing *Helicoverpa* over the past 30 years, i.e. product failures and the need to replace waning products with new (usually more expensive) ones.

Bollgard®II has shown it has the capacity to act as a nursery for natural enemies of pests, including spiders, some predatory bugs and beetles, and *Trichogramma* wasps. However the extent predators and parasitoids move from Bollgard®II into surrounding conventional cotton is still uncertain.

Graphs from field trials: Typical examples of predator numbers in differently managed conventional cotton and Bollgard®II.

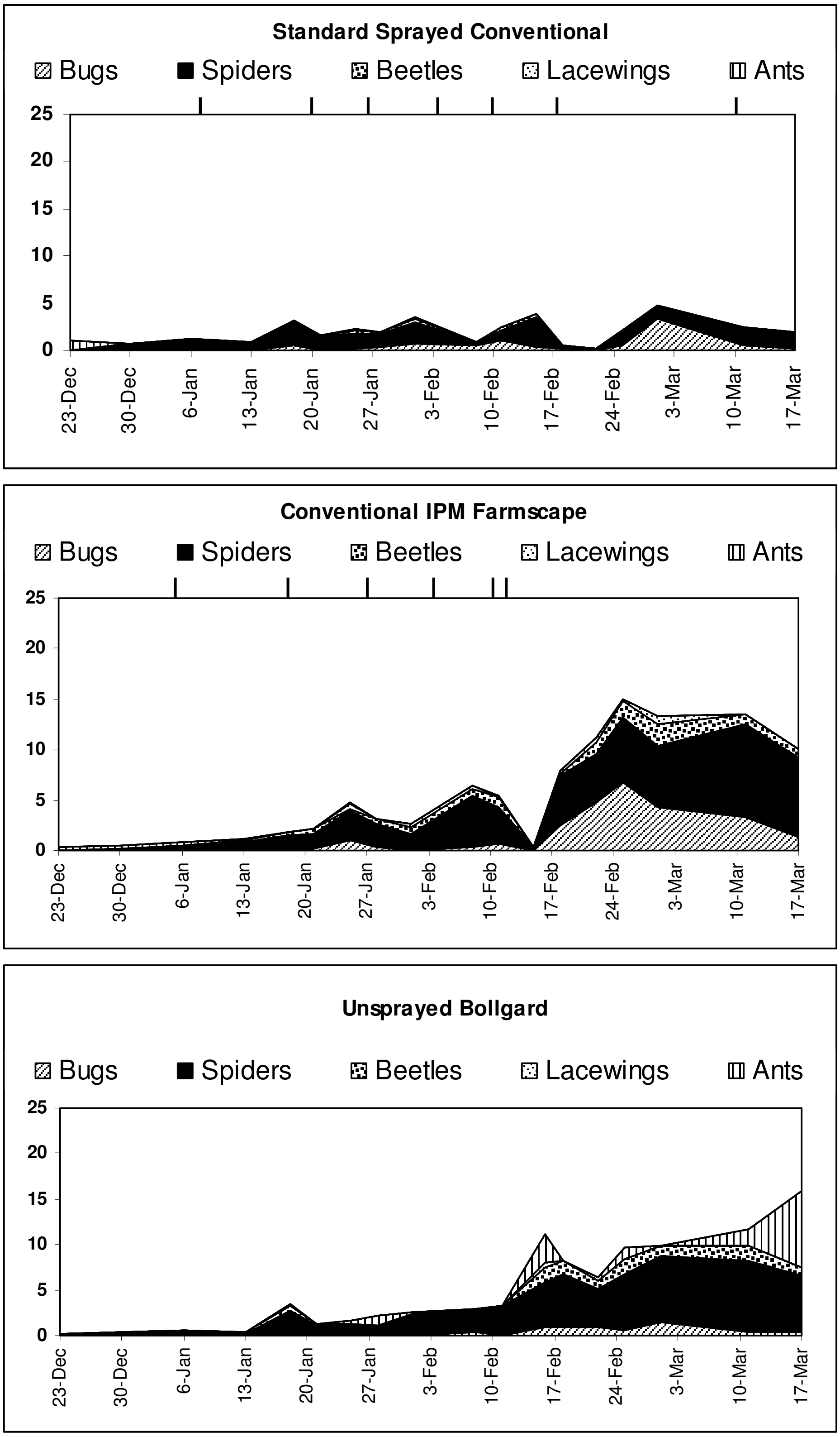


Figure 1: The numbers of predators per metre in dryland cotton at "Coondarra" during 2004/05. The vertical lines refer to applications of insecticides. Data are the means of six beat sheet samples. The conventional IPM farmscape was managed with selective insecticides and intercropped with sorghum.

Figures from field trials: Typical examples of damsel bug numbers found in unsprayed and sprayed Bollgard®II.

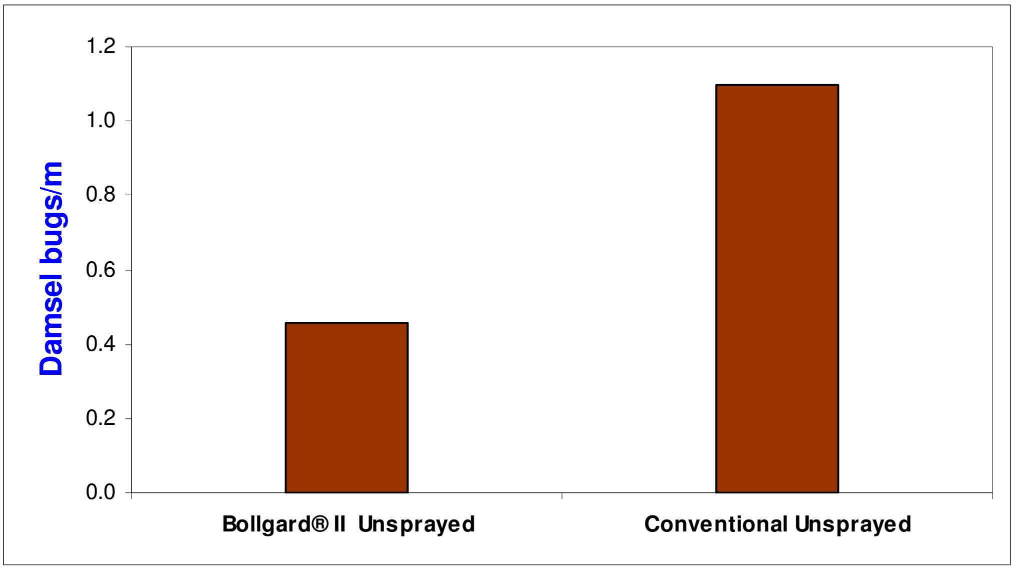
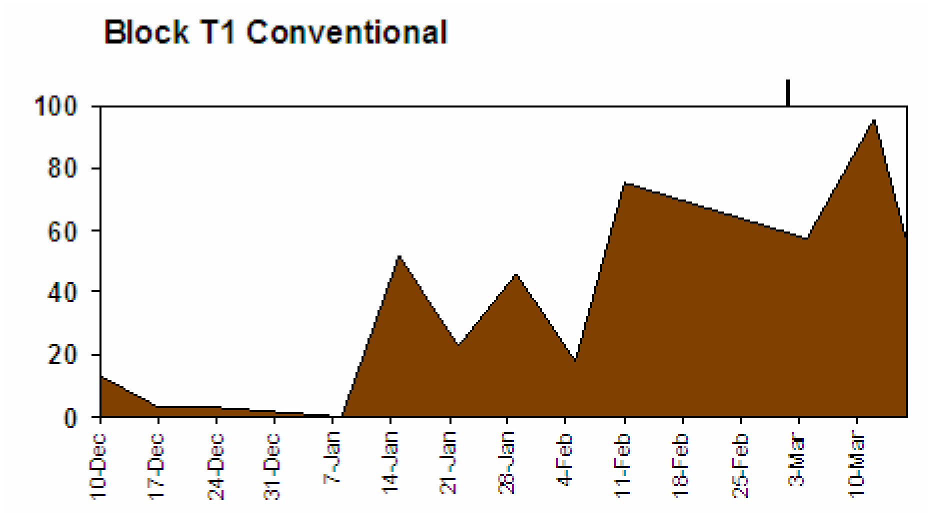


Figure 2: The average number of damsel bugs in cotton at “Coondarra” over the 2005/06 season. The data are the mean numbers per metre from 140 beat sheet samples.

Figures from field trials: Typical examples of percentage parasitism in, Bollgard®II and in low-sprayed sprayed conventional cotton



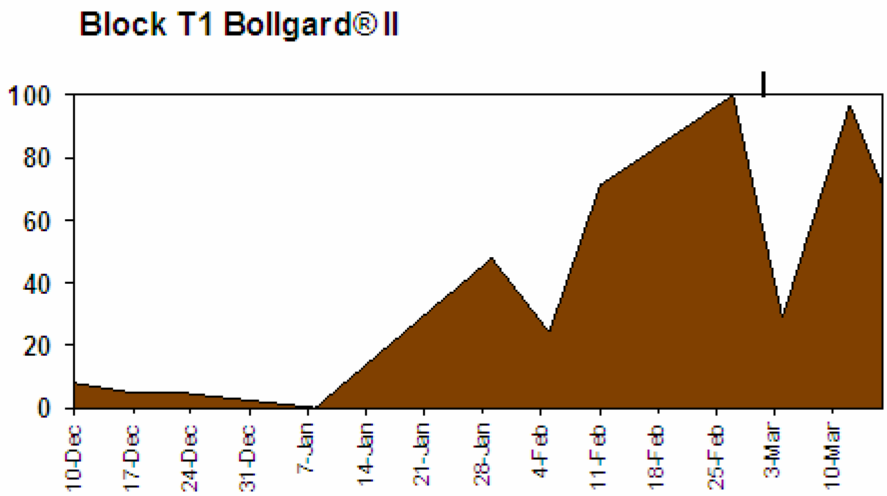
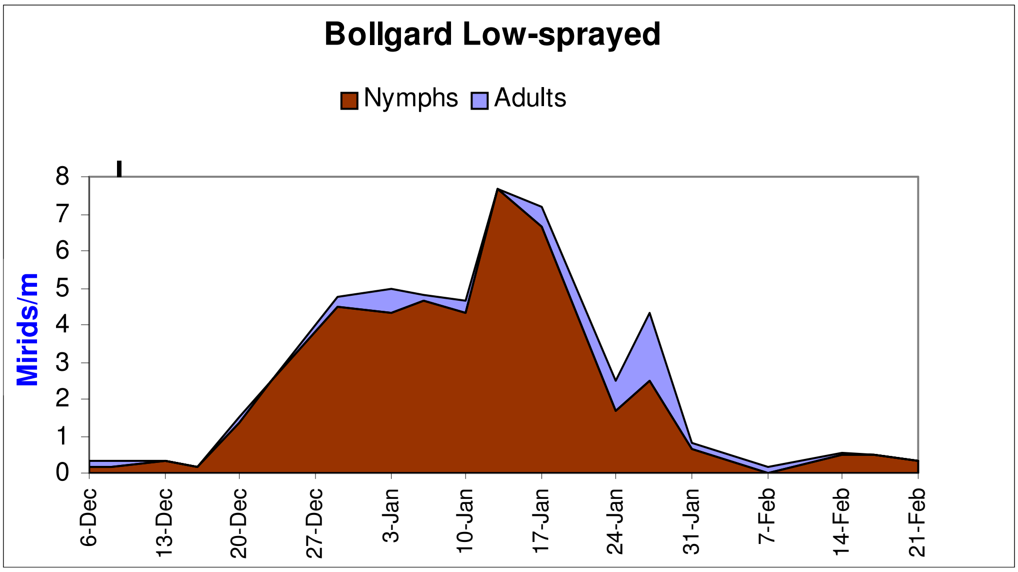


Figure 3: The levels of *Helicoverpa* egg parasitism (%) in Bollgard®II and Conventional cotton at "Tyunga" during 2003/04. The vertical lines refer to application of acetamiprid (Intruder®) @ 75 mL/ha. Data are for naturally laid brown eggs collected from each cotton block

Figures from field trials:: Typical examples of mirid numbers in unsprayed and sprayed Bollgard®II.



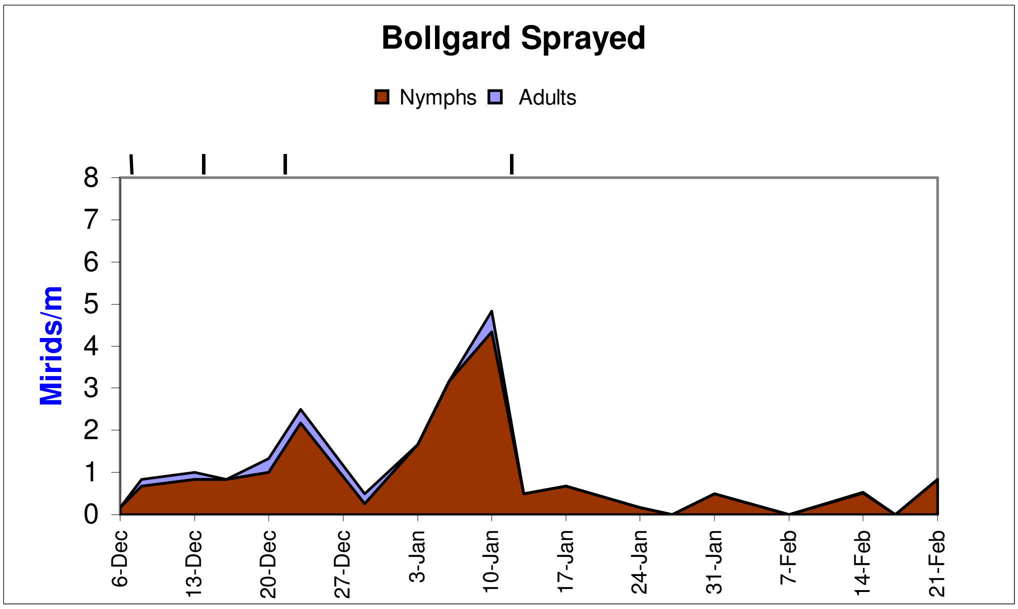


Figure 4: The numbers of green mirids per metre in dryland cotton at "Coondarra" during 2005/06. The vertical lines refer to applications of insecticides. Data are the means of six beat sheet samples.

Figures from field trials: Typical examples of predator numbers found in Bollgard®II, conventional cotton and farmscaped cotton

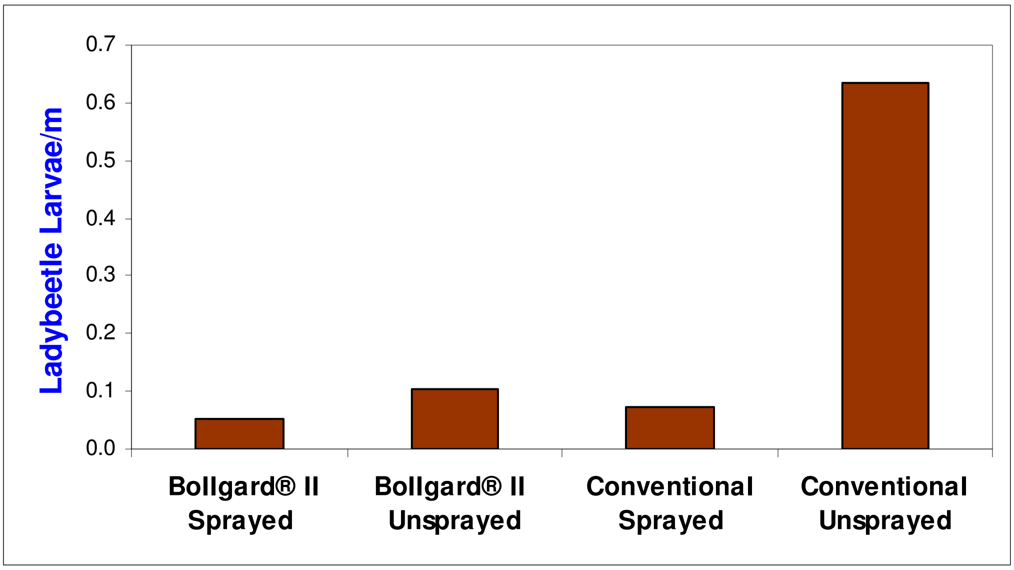


Figure 5: The average number of ladybeetle larvae in cotton at "Coondarra" during 2005/06. The data are the mean numbers per metre from 140 beat sheet samples. Both conventional cotton blocks were farmscaped with sorghum.

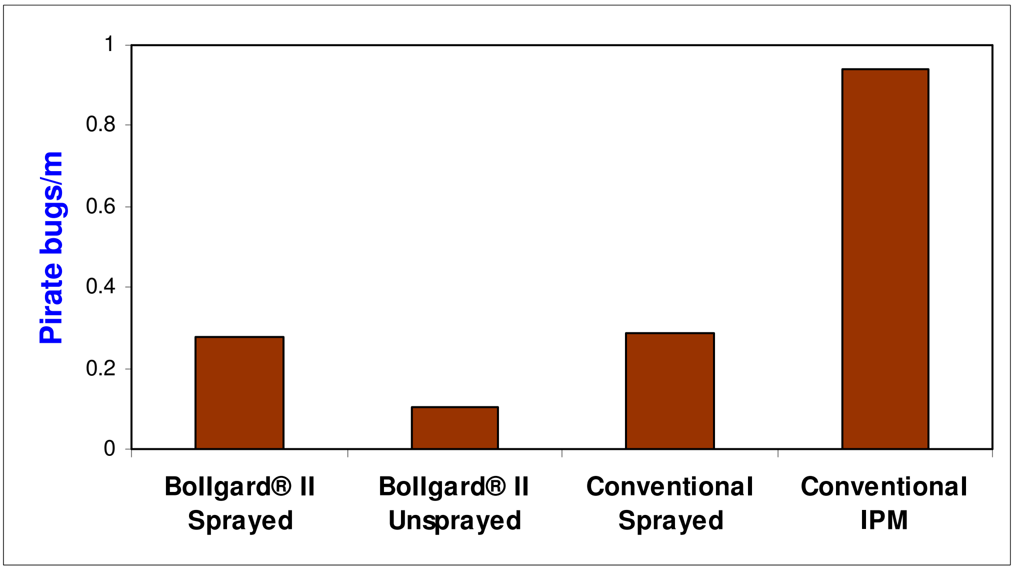


Figure 6: The average number of pirate bugs in cotton at "Coondarra" during 2004/05. The data are the mean numbers per metre from 114 beat sheet samples. The conventional IPM block was farmscaped with sorghum.

Table 1: Insecticide Ratings against *Trichogramma pretiosum*

Active ingredient	Insecticide trade name	Rate tested	Target Pest	Rating
Indoxacarb	Steward	0.85 L/ha	*Helicoverpa*/Mirids	94.2
Water	*Control*	*N/A*	*N/A*	93.9
Diafenthiurion	Pegasus	0.8 L/ha	Aphids/Mites/Whitefly	92.7
Methoxyfenozide	Prodigy	2.5 L/ha	*Helicoverpa*	91.5
Pymetrozine	Fulfil	0.4 kg/ha	Aphids	87.3
Amitraz	Ovasyn	2 L//ha	*Helicoverpa*	84.9
Pirimicarb	Pirimor	0.75 kg/ha	Aphids	74.0
Fipronil	Regent	0.125 L/ha	Mirids/Thrips	72.9
Imidaclopird	Confidor	0.25 L/ha	Aphids/Mirids/Thrips	67.0
Thiodicarb	Larvin	2.5 L/ha	*Helicoverpa*	65.4
Dimethoate	Rogor	0.5 L/ha	Aphids/Mirids/GVB/Mites/Thrips	58.7
Acetamiprid	Intruder	0.2 L/ha	Aphids	53.7
Spinosad	Tracer	0.2 L/ha	*Helicoverpa*	50.3
Emamectin benzoate	Affirm	0.7 L/ha	*Helicoverpa*	48.0
Abamectin	Agrimec	0.6 L/ha	*Helicoverpa* punctigera/Mites	45.7
Endosulfan	Endosulfan	0.2 kg/ha	Aphids/*Helicoverpa*/Mirids/Thrips/GVB	29.2
Clorfenapyr	Intrepid	1.1 L/ha	Mites/*Helicoverpa*	27.7
Methomyl	Lannate	2.4 L/ha	*Helicoverpa*	24.3
Thiamethoxam	Actara	2.1 L/ha	Aphids/Leafhopper	23.2
Bifenthrin	Talstar	0.8 L/ha	*Helicoverpa*/Mirids/Mites	18.0
Chlorpyrifos-methyl	Rescue	2 L/ha	Aphids/*Helicoverpa*/Mirids	4.1

Mortality compared with control		
Dark green	**<10%**	**Very low**
Green	**10-20%**	**Low**
Yellow	**20-40%**	**Moderate**
Orange	**40-60%**	**High**
Red	**>60%**	**Very High**

Colors match Cotton IPM Guidelines

Ratings are the percentage survival and emergence of *Trichogramma* when the data from six different assessments were averaged; these six assessments included:

- The impact of insecticide residues on cotton leaves against adult *Trichogramma* 0, 1, 2 and 5 days after insecticide applications
- The impact of directly applying insecticides on adult *Trichogramma* and
- The emergence of *Trichogramma* from parasitised *H. armigera* eggs that had been sprayed with insecticides.

References

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Prasifka J.R., Heinz K.M. and Sansone C.G. (2004) Timing, magnitude, rates and putative causes of predator movement between cotton and grain sorghum fields. *Environ. Entomol.* 33: 282-290

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Fye R.E. and Carranza R.L. (1972) Movement of insect predators from grain sorghum to cotton. *Environ. Entomol.* 6: 790-791

Scholz, B., Cleary, A. and Lloyd, R. (2001). Sheet unbeatable for sampling predators in cotton. *Australian Cottongrower* 22: 14-17

Yang, Y., Yu, Y., Ren, L., Shao, Y., Qian, K. and Zalucki, M.P. (2005). Possible incompatibility between transgenic cottons and parasitoids. *Aust. J. Ent.* 44:442-445.

Outcomes

Economic: The research brought to light that sound pest management practices, based on the principles of integrated pest management, are often as profitable as high insecticide use approaches, particularly in dryland cotton management. The project also highlighted the importance of insecticide choice for controlling pests in Bollgard®II. In particular mirid sprays were often unnecessary and then contributed to aphid or whitefly infestations which were costly to manage.

Essentially the research has shown by combining IPM principles and insecticides that competitive yields can be gained with lower spray costs. Intercropping can reduce the number of sprays needed in conventional cotton by combining softer chemical sprays with the creation of a nursery crop like sorghum.

Environmental: The research highlights the value of non-chemical approaches to pest management, in particular those practices where natural enemies (predators and parasitoids) are utilised in pest management. The research has shown that it is possible to use environmentally sustainable approaches to aid pest management based on ecological principles instead of toxicological principles.

Social: A key component of the project involved working with regional IPM/AWM groups, and collaborating on commercial farms with leading growers and consultants. This fostered regional co-operation and capacity building, evidenced by neighbouring farmers applying farmscaping principles after talking with our collaborators.

To our knowledge there are no IP issues related to this project.

Conclusions

- Newly hatched *Helicoverpa* larvae were regularly found in the Bollgard®II, but these died and did not grow into larger larvae. Some larger larvae were found late in each season in Bollgard®II.

- The Bollgard®II had markedly fewer sprays for *Helicoverpa* than conventional cotton. However, Bollgard®II received between 4 and 6 applications of insecticides for bug pests.

- Though water availability was variable across years, there was no difference in yield when Bollgard®II was left unsprayed for green mirids in four dryland trials. Insecticides were used needlessly to control mirids. In particular dimethoate and fipronil applications reduced predator numbers and may have contributed to aphid and whitefly infestations in Bollgard®II.

- Components of the predator complex (damsel bugs and lacewings) were significantly lower in the Bollgard®II than in unsprayed or low sprayed conventional cotton. Spiders were the most abundant predatory group in all cotton fields.

- Bollgard®II did not have any apparent impact on parasitism levels by *Trichogramma.* Parasitism consistently exceeded 90% each season in Bollgard®II crops - comparable to unsprayed and IPM managed conventional cotton.

- Farmscaping trials showed that sorghum and maize acted as a nursery for a number of important natural enemies including ladybird beetles, some predatory bugs, spiders and *Trichogramma* wasps. There was evidence that beneficial diversity and abundance was enhanced in cotton by planting cotton adjacent to sorghum and maize.

- Insecticide trials showed that few products are compatible with *Trichogramma*. Though eggs provided good protection from most products, insecticides with long residual activity killed wasps as they ate through the egg chorion to emerge. The choice of insecticide is of vital importance if *Trichogramma* are to be utilized in cotton pest management.

Extension Opportunities

The principal researchers have taken an active role communicating their research findings as evidenced by the following list. Despite both researchers resigning from DPI&F, the broader messages of their research will continue to be communicated to Industry through various forums.

<u>Meetings attended by Brad Scholz and Nathaniel Parker</u>

1. ***15 July 2003 – Jimbour:*** Brad attended an IPM meeting at St. John Kent's, Jimbour. The meeting was organised by Austin McLennan and Melina Miles, and was attended by Dave Murray, St. John Kent, David Alexander and John Fuelling.
2. ***23-24 July 2003 – Armidale:*** Brad presented a paper at the Cotton CRC review titled "The role of natural enemies in dryland cotton IPM."
3. ***31 July 2003 – Evanslea:*** Brad attended the Evanslea IPM group meeting and spoke briefly about findings from the previous season, and proposed work under the new project.
4. ***11 August 2003 – Jimbour:*** Brad and Nat attended a meeting with St. John Kent to discuss trial plans at his farm for the 2003/04 season. Bernie Franzmann, Lawry Smith also attended.
5. ***14 August 2003 – St George:*** Brad gave a presentation on "Know your Beneficials" at Mark Hickman's *Cotton IPM Short Course* workshop at the St. George RSL club.

6. ***27 August 2003 – Narrabri:*** Brad gave a presentation called "*Trichogramma*: Small wasps that pack a big punch" at the CCA Cotton Production Seminar at the Narrabri Crossing Theatre.
7. ***10 September 2003 - Macalister*** Nat attended a grower meeting organized by Austin McLennan. Nat assisted by taking notes, cooking and discussing trial options with consultants.
8. ***11 September 2003 - Norwin*** Nat attended a grower meeting organized by Austin McLennan. Nat assisted by taking notes, cooking and discussing trial options with consultants.
9. ***28 January 2004 – Brookstead:*** Brad and Nat attended a field day at Paul & Georgina Krieg's property, 'Glen Royal', organized by Austin McLennan. Brad and Nat assisted in a *Trichogramma* monitoring activity. Participants collected brown *Helicoverpa* eggs from cotton and transferred them to plastic egg collection trays to determine the levels of egg parasitism.
10. ***9 June 2004 – Dalby:*** Brad attended the CSD Information Update at the Dalby RSL club.
11. ***16 July 2004 – Toowoomba:*** Brad spoke to Mike Horan MP about IPM, AWM and biological pest control.
12. ***5 August 2004 – Inverai Hall:*** Brad spoke about *Trichogramma* at the Brigalow-Jimbour area wide management meeting organised by Nevin Olm and Landmark. The meeting was well attended and there was a lot of interest in using *Trichogramma* in IPM programs.
13. ***12 August 2004 – Broadbeach:*** Brad presented a "*Trichogramma*" hands-on session at the 12th Australian Cotton Conference held at the Gold Coast Convention Centre.
14. ***2 September 2004 – Narrabri:*** Brad spoke about beneficial insects at John Stanley's Cotton Production course at the Australian Cotton Research Institute at Narrabri.
15. ***18 November 2004 – Norwin:*** Brad attended the "Communicating for improved Insect Pest Management" information session and BBQ at the Norwin Lutheran Church Hall.
16. ***13 December 2004 – Warra:*** Brad attended Mark Hickman's *Dalby Cotton IPM Short Course* field day at Glenn Bischof's property "Arrawatta". Brad spoke about beneficials and demonstrated how to use a beat sheet for sampling beneficials and mirids.
17. ***22 December 2004 – Brookstead***: Brad and Nat attended a Bollgard®II Farm Walk organised by Greg Salmond at "Melrose" near Brookstead. Brad and Nat spoke about beneficials and demonstrated how to use a beat sheet for sampling beneficials and mirids, and how to collect *Helicoverpa* eggs to assess egg parasitism.
18. ***25 January 2005 – Jimbour:*** Brad and Nat attended a *Trichogramma* workshop, organised by Austin McLennan, at Roly Schmelzer's property 'Obergurgl' near Jimbour. They assisted in demonstrating how to collect *Helicoverpa* eggs to assess egg parasitism, and answered a range of questions on *Trichogramma*.
19. ***4 February 2005 – Warra:*** Brad and Nat attended the second field day of Mark Hickman's *Dalby Cotton IPM Short Course* at Glenn Bischof's property "Arrawatta". Brad and Nat spoke about beneficials and demonstrated how to use a beat sheet for sampling beneficials. There was also an in-field demonstration of Magnet.
20. ***9 February 2005:*** Brad appeared on the CSD *Web on Wednesday* feature where he spoke on "*Trichogramma* – Small wasps with big hearts".
21. ***9 March 2005 – Goondiwindi:*** Brad presented a paper titled "Sampling and utilising *Trichogramma* and other parasitoids in sorghum" at the Grains Research Update that was held at the Goondiwindi Community Centre.

22. ***26 May 2005 – Moree:*** Brad attended the Cotton Trade Show and manned the CRDC stand from 11:00 am to 2:00 pm.
23. ***2 June 2005 – Brookstead:*** Brad attended a joint meeting of the Pampas, Tummaville and Brookstead IPM groups, organised by Austin McLennan.
24. ***27th July 2005 – IPM workshop:*** Nat presented a "*Trichogramma Update*" detailing Brad and Nat's past two seasons work on *Trichogramma*, Bollgard®II and farmscaping at the 8th IPM Forum held in Brisbane.
25. ***12th October 2005 –*** Nat attended a grower/consultant meeting where Richard Llewellyn gave a presentation on *Trichogramma*. Nat gave a quick presentation on field work and utilizing farmscapes to encourage the build up of *Trichogramma and* predator populations.
26. ***29th November 2005 –*** Nat attended a meeting with St John Kent (cotton grower), John Fuelling (consultant) and Jackie Rickters (an industrial placement student), where they discussed field trials for the season and marked out treatment sites with St John.
27. **5 December 2005 –** Nat attended a meeting with Austin McLennan and David Murray. They meet with AWM and IPM groups to discuss the coming season and their hopes and plans for pest management.
28. ***7th February 2006-*** Nat attended a grower/consultant meeting, where St John Kent and he discussed farmscaping with grain/cotton growers and provided information booklets on IPM and utilizing natural enemies.

List of publications arising from the research project and related collaborations.

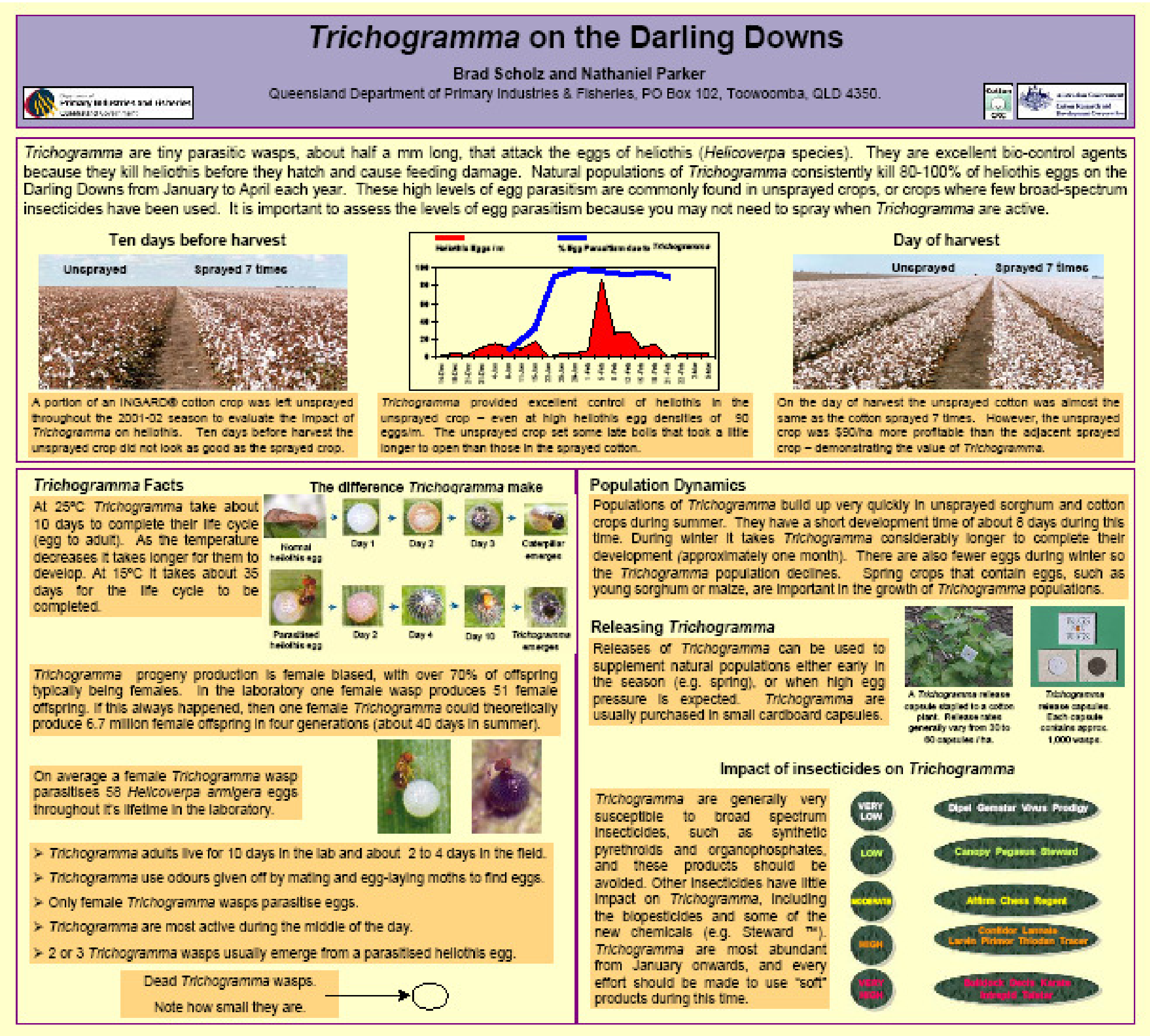
1. M-L Johnson, S. Armitage, B. Scholz and M.P. Zalucki (2006). Predator presence moves *H. armigera* larvae to distraction. *Journal of Insect Behavior* In press.
2. M-L. Johnson, D. Merrit, B. Cribb, M.P. Zalucki and B. Scholz (2006). Hidden trails: The use and quantification of silk trails by Lepidopteran larvae on different substrates. *Entomologia Experimentalis et Applicata* In press.
3. Whitehouse, M.E.A., Hardwick, S., Scholz, B.C.G., Annells, A.J., Ward, A., Grundy, P.J. and Harden, S. (2006). Evidence of a latitudinal gradient in spider diversity in Australian cotton. *Ecography* In press.
4. Mansfield, S., Scholz, B., Armitage, S., and Johnson, M.L. (2006). Effects of diet, temperature and photoperiod on development and survival of the bigeyed bug, *Geocoris lubra*. *Biocontrol* In press.
5. Wade, M.R., Scholz, B.C.G., Lloyd, R.J., Cleary, A.J., Franzmann, B.A. and Zalucki, M.P. (2006). Temporal variation in arthropod sampling effectiveness: the case for using the beat sheet method in cotton. *Entomologia Experimentalis et Applicata* 120: 139-153.
6. Scholz, B. (2005). Good bugs reduce chemicals on farms. *Nature Calls* 4: 3.
7. Scholz, B. and Parker, N. (2004). *Trichogramma*: Small wasps that pack a big punch. *Australian Cottongrower* 25(4): 46-50.
8. Dillon, M. and Scholz, B. (2004). Fire ants: An invader we don't want in cotton. *Australian Cottongrower* 24(7): 16-17.
9. Scholz, B. and Parker, N. (2004). The nursery value of sorghum intercropped with cotton - the effects on helicoverpa egg parasitism and predator abundance in cotton. *Proceedings of the Twelfth Australian Cotton Conference*, Broadbeach, Queensland, 10-12 August, 2004, pp.639-647.
10. Scholz, B. and Parker, N. (2004). Evaluations of different release rates of *Trichogramma pretiosum* against *Helicoverpa armigera* eggs in sorghum and cotton.

Proceedings of the Twelfth Australian Cotton Conference, Broadbeach, Queensland, 10-12 August, 2004, pp.649-656.

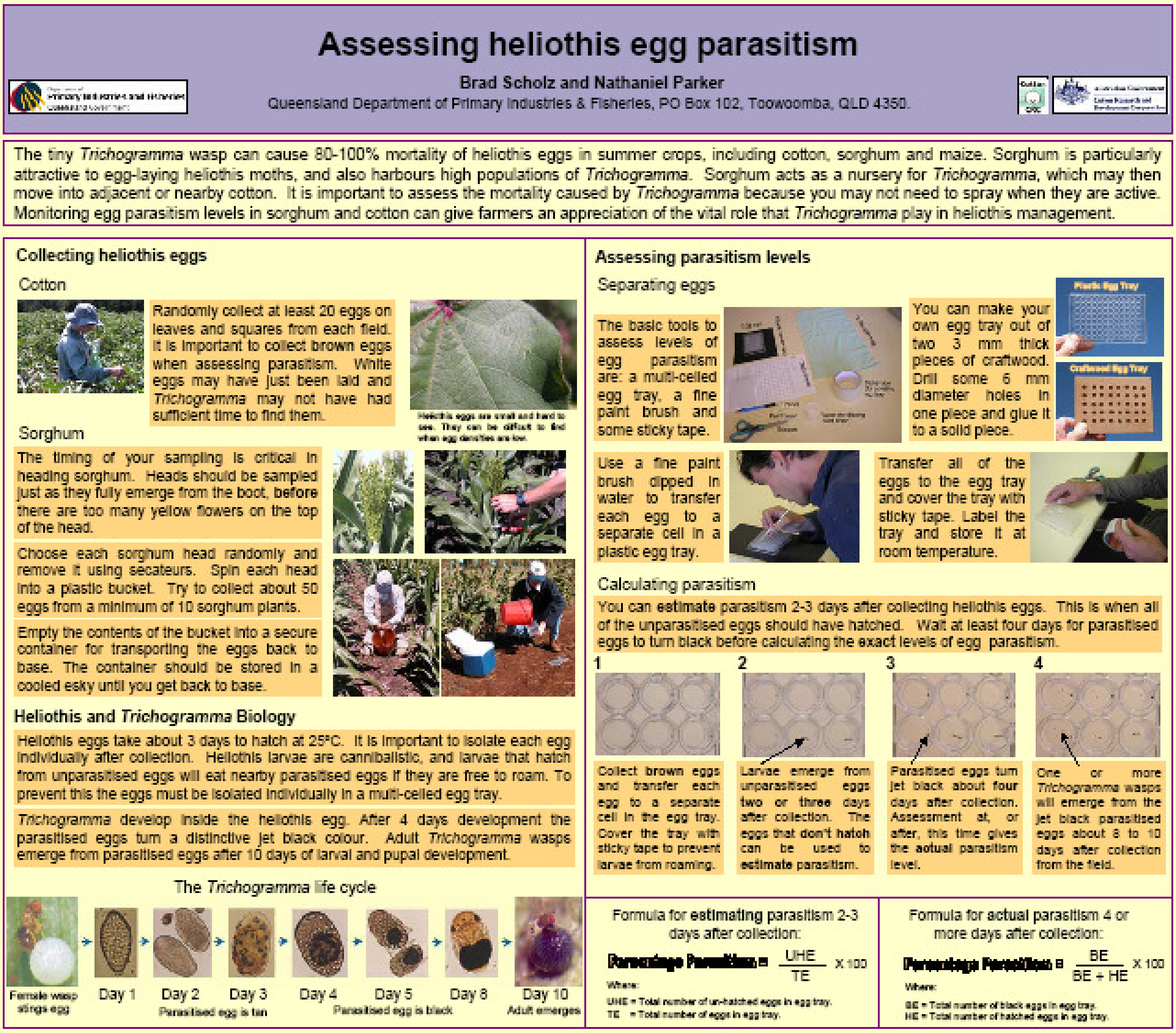
11. Parker, N. and Scholz, B. (2004). A survey of egg parasitoids in sorghum on the Darling Downs. *Proceedings of the Twelfth Australian Cotton Conference*, Broadbeach, Queensland, 10-12 August, 2004, pp. 657-660.
12. Scholz, B. and Parker, N. (2004). Lifespan, parasitism levels and progeny production of *Trichogramma pretiosum* reared on *Helicoverpa armigera* eggs in the laboratory. *Proceedings of the Twelfth Australian Cotton Conference*, Broadbeach, Queensland, 10-12 August, 2004, pp.661-665.
13. Parker, N., Scholz, B. and Mensah, R. (2004). An evaluation of the toxicity of two paraffin oils (Biopest(r) and Canopy(r)) on *Trichogramma pretiosum*. *Proceedings of the Twelfth Australian Cotton Conference*, Broadbeach, Queensland, 10-12 August, 2004, pp. 667-673.

Posters presented at conferences

Trichogramma on the Darling Downs



Assessing heliothis egg parasitism



Have you developed any online resources and what is the website address?

Not at this stage.

Acknowledgements

The Australian Cotton Research & Development Corporation is gratefully acknowledged for funding this project.

Brad and Nat have really appreciated the support and friendship from the DPI&F Entomology Staff at Tor Street in Toowoomba.

It has been great to work with cotton growers and consultants who see the importance IPM continues to play in cotton farming systems. These include: Matthew Holding, John Fuelling, St. John Kent, Anthony McConville, Neil Nass, Johannes Roellgen, Brett and Glen Porter and Andrew Speed.

Part 4 – Final Report Executive Summary

This project focused on developing and testing best management options for key pests in Bollgard®II and conventional cotton. The influence of the surrounding habitat (Bollgard®II & conventional cotton, sorghum and maize) on natural enemy abundance and diversity was also investigated.

Field sampling showed that the *Bt* toxin was effective against *Helicoverpa,* providing a high level of efficacy season long. The beneficial complex between conventional cotton and Bollgard®II was assessed. Species diversity and abundance in Bollgard®II was higher than that in conventional cotton sprayed with broad-spectrum insecticides. However it was found that Bollgard®II contained significantly fewer predatory bugs and lacewings than low-sprayed or IPM sprayed conventional cotton. Bollgard®II did not have any apparent impact on parasitism levels by *Trichogramma*, a key natural enemy of *Helicoverpa*.

The role of landscape diversity in augmenting natural enemies was investigated by intercropping sorghum, maize and cotton. Sorghum was found to contain many key natural enemies of *Helicoverpa* and aphids. *Trichogramma* parasitism was found to be higher in cotton adjacent to maize with evidence of decreasing parasitism approximately 50 metres from the cotton - maize interface. Various trials conducted during the project gave evidence that sorghum – cotton farmscapes encouraged numbers of ladybirds (particularly ladybird larvae), pirate bugs and spiders and increased *Trichogramma* parasitism in adjacent cotton. The abundance of predators in sorghum was variable across years, however even when numbers were low there was evidence that the sorghum was contributing to insect diversity and abundance in adjacent cotton. This supports the hypothesis that natural enemies may use sorghum or maize as a haven and disperse into nearby cotton fields.

The most serious pest of Bollgard®II on the Southern Downs over the three years of the project was green mirids. Each year of the project commercially managed dryland Bollgard®II was compared to an unsprayed crop to assess economic damage from mirids. Though water availability was variable (high and low) across years, there was no difference in yield making unsprayed Bollgard®II the more economical crop. Insecticides used to needlessly control mirids, decimated natural enemies, potentially contributing to aphid and whitefly infestations in Bollgard®II.

Though in their infancy, farmscaping trials were encouraging and the cotton industry should continue to promote this method of enhancing natural enemies in Bollgard®II and conventional cotton. For Bollgard®II these practices should reduce pest infestations i.e. aphids and whitefly, and may also play an important role in delaying *Helicoverpa* resistance to Bollgard®II.